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SECTION 1.7
TABLE 1.7-1 SO_x EMISS. FACTOR

Information Circular 8650

Technology and Use of Lignite

Proceedings: Bureau of Mines-University of North Dakota Symposium, Grand Forks, N. Dak., May 9-10, 1973

Compiled by Gordon H. Gronhovd and Wayne R. Kube
Grand Forks Energy Research Laboratory, Grand Forks, N. Dak.

UNITED STATES DEPARTMENT OF THE INTERIOR
Rogers C. B. Morton, Secretary

BUREAU OF MINES
Thomas V. Falkie, Director

SOME STUDIES ON STACK EMISSIONS FROM LIGNITE-FIRED POWERPLANTS

by

G. H. Gronhovd,[20], P. H. Tufte,[21] and S. J. Selle[22]

Introduction

Stack emission limits for new stationary sources of greater than 250-MMBtu/hr input were promulgated on a national basis by the Environmental Protection Agency (EPA) in 1971.[23] These standards include limits for SO_2, NO_x, and particulate matter and are applicable to all plants constructed or significantly modified after August 17, 1971. In addition, there are State, and sometimes local, regulations pertaining to emissions from new and existing powerplants.

Little information is available in the literature on the quantity and quality of stack emissions from boilers burning North Dakota lignite. For this reason NO_x limits for lignite-fired plants were not specified in the National Emission Standards. Lignite from the Northern Great Plains Province is currently used in plants totaling about 1,200-MW capacity, and plants now under construction will increase the total to 2,000 MW by 1975. During the past 8 years but most actively since 1970, the Bureau of Mines has conducted field tests in which data on furnace exit and stack emissions from lignite fired plants have been obtained. This report presents data on SO_2, SO_3, NO_x, and solid particulate emissions obtained in these field tests. Such data should be of value to those responsible for the design, procurement, or operation of air pollution control devices for lignite-burning plants.

Acknowledgments

The cooperation of Otter Tail Co., Basin Electric Coop., Central Power Electric Coop., and Minnkota Power Coop. in permitting tests at their plants is gratefully acknowledged. Without their support the tests would not have been possible.

Powerplants Tested

Tests were conducted at three pulverized-coal-fired (pc-fired) plants, one cyclone-fired plant, and one spreader-stoker-fired plant, each burning lignite from a different mine in North Dakota. Information on each of the plants tested and the source of lignite burned are given in table 5. This report includes data from a total of 46 test days, 39 of which were with pc firing.

[20] Chief.
[21] Chemical engineer.
[22] Mechanical engineer.
All authors are with the Grand Forks Energy Research Laboratory, Bureau of Mines, Grand Forks, N. Dak.

[23] Environmental Protection Agency. Standards of Performance for New Stationary Sources. Federal Register, v. 36, No. 247, Dec. 23, 1971, pp. 24876-24895.

TABLE 5. - Powerplants included in emission studies

Plant name	Hoot Lake	Leland Olds	Wm. J. Neal	Milton R. Young	F. P. Wood
Plant location	Fergus Falls, Minn.	Stanton, N. Dak.	Voltaire, N. Dak.	Center, N. Dak.	Grand Forks, N. Dak.
Company	Otter Tail Power Co.	Basin Electric Power Coop.	Central Power Electric Coop.	Minnkota Power Coop.	Minnkota Power Coop.
Size of installations tested, MW.	50	215	20	235	12
Type of firing	Pulverized coal.	Pulverized coal.	Pulverized coal.	Cyclone burner	Spreader stoker.
Burner location	Tangential	Front and rear walls.	Front wall	Front wall	
Source of lignite	Beulah mine and Gascoyne mine of Knife River Coal Mining Co.	Glenharold mine of Consolidation Coal Co.	Velva mine of Consolidation Coal Co.	Center mine of Baukol-Noonan, Inc.	Larson mine of Baukol-Noonan, Inc.
Dates of tests	1965, 1966, 1970, 1972	1970, 1971	1971	1970, 1971, 1972	1971, 1972
Type fly ash collector during tests.	Cyclone, pilot ESP,[1] Commercial ESP.[1]	Cyclone, pilot ESP.[1]	Cyclone	Cyclone	Cyclone.

[1]ESP = electrostatic precipitator.

Calculation Methods and Test Procedures

General

Principal emphasis was on the measurement of SO_2 emissions and their relationship to sulfur level in the coal burned. For such a study a complete ash and sulfur balance on the boilers tested would have been desirable. However, the difficulty and expense involved in collecting, weighting, and sampling large quantities of ash (15 to 20 tons per hour for a 200-MW unit) makes a complete sulfur balance quite impractical within the framework of a limited program. Data on SO_2 are based only on sampling of the coal feed and analysis of SO_2 in the flue gas.

Calculation Method

The SO_2 emission per million Btu input and the percentage of input sulfur in the lignite that is emitted as SO_2 can be calculated from the coal and the flue gas analyses without knowing the weights of coal burned or volume of flue gas produced. Given the carbon, sulfur, and heating value of the coal and the Orsat analysis of the flue gas, a balance on the carbon, assuming that all of the carbon in the coal appears as CO_2 and CO in the flue gas, yields the following equations:

$$\text{lb } SO_2/\text{MMBtu} = 5.33 \times \frac{C}{(CO_2 + CO)} \left(\frac{ppm}{HHV}\right), \quad (1)$$

and

$$S.E. = 2.67 \times 10^{-2} \times \frac{C}{(CO_2 + CO)} \left(\frac{ppm}{S}\right), \quad (2)$$

where ppm = parts per million of SO_2 in the flue gas, volume per volume on a dry basis;

CO_2 + CO = vol-pct in flue gas from Orsat analysis;

C = wt-pct carbon from the ultimate analysis of fuel;

S = wt-pct sulfur from ultimate analysis of fuel;

HHV = higher heating value of the coal, Btu/lb;

and S.E. = pct of input sulfur in the coal emitted as SO_2.

Data from ultimate analysis and heating value should be on the same basis--as received or moisture free.

A typical North Dakota lignite[34] has 65 pct carbon, 10 pct ash, and 10,800 Btu/lb on a dry basis. Using these values the pounds of SO_2 per million

[34] Sondreal, E. A., W. R. Kube, and J. L. Elder. Analysis of the Northern Great Plains Province Lignites and Their Ash: A Study of Variability. BuMines RI 7158, 1968, 94 pp.

Btu can be calculated for various sulfur levels. These data along with corresponding parts per million SO_2 in the flue gas, based on 30 pct excess air, have been plotted in figure 54. For each sulfur level the percentage of SO_2

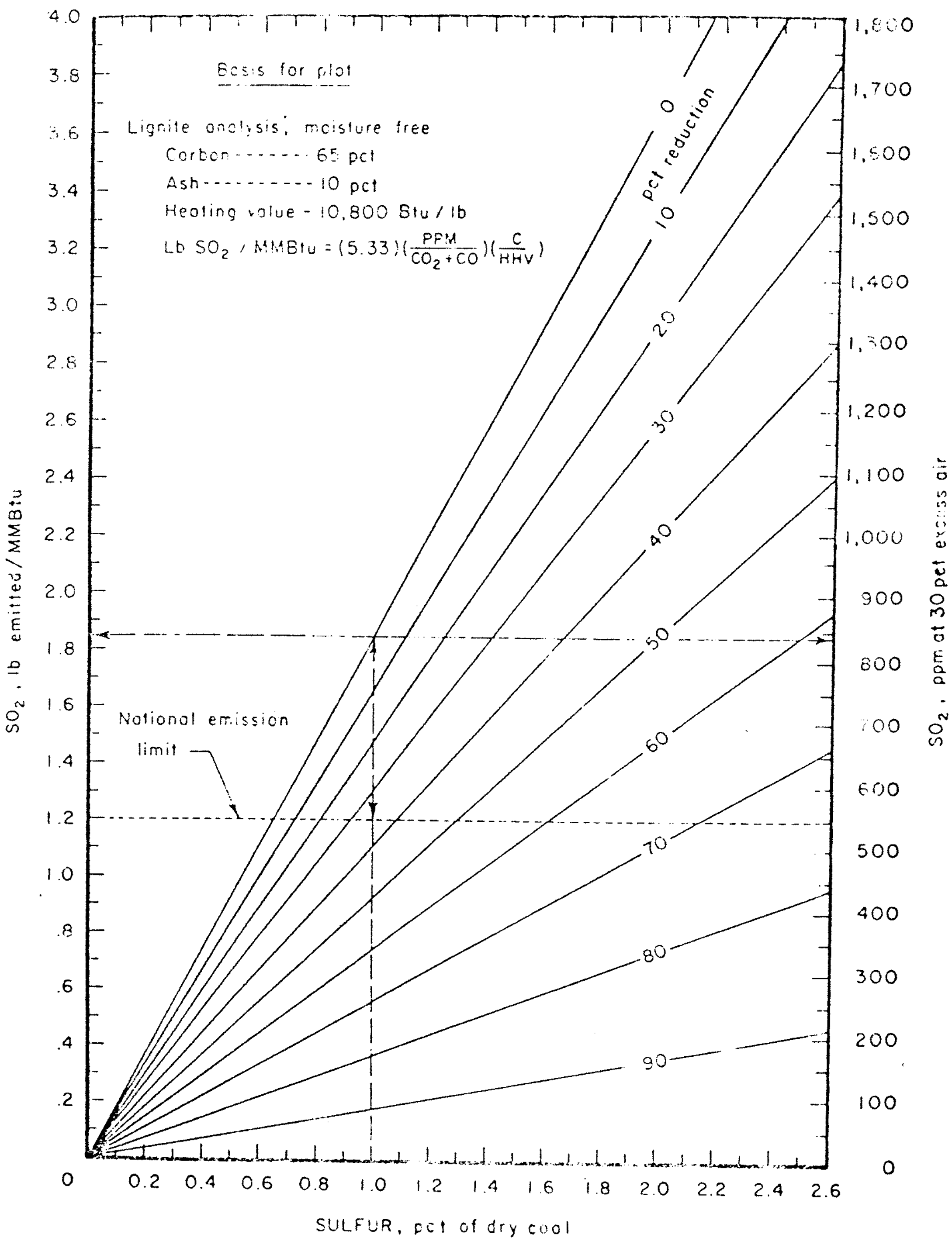

FIGURE 54. - Chart for determination of sulfur emissions and percentage removal required to meet national emission limit.

removal required to meet the 1.2 lb/MMBtu national emission limit is given by the lines of percent removal. For example (illustrated by the dashed lines on the chart), a lignite having 1-pct-sulfur content on a dry basis would have an equivalent SO_2 in the flue gas of 1.85 lb/MMBtu or 837 ppm. A 37-pct reduction in SO_2 would be required to meet the national emission limit.

The NO_x emission rate reported as NO_2 can be calculated by a similar method as for SO_2, using the equation

$$\text{lb } NO_x/\text{MMBtu} = 3.83 \times \frac{C}{(CO_2 + CO)}\left(\frac{\text{ppm}}{\text{HHV}}\right), \tag{3}$$

where ppm = parts per million of NO_x in the flue gas, volume per volume on a dry basis.

Coal Sampling and Analysis

In sampling the lignite feed to the boilers, the objective was to collect a representative sample that would give an accurate value of the sulfur input during the SO_2 sampling period. The coal handling equipment and the facilities for sampling varied from plant to plant. The usual sampling procedure was to collect grab samples from each coal feeder at 1/2-hour intervals and combine these samples for determination of average sulfur content.

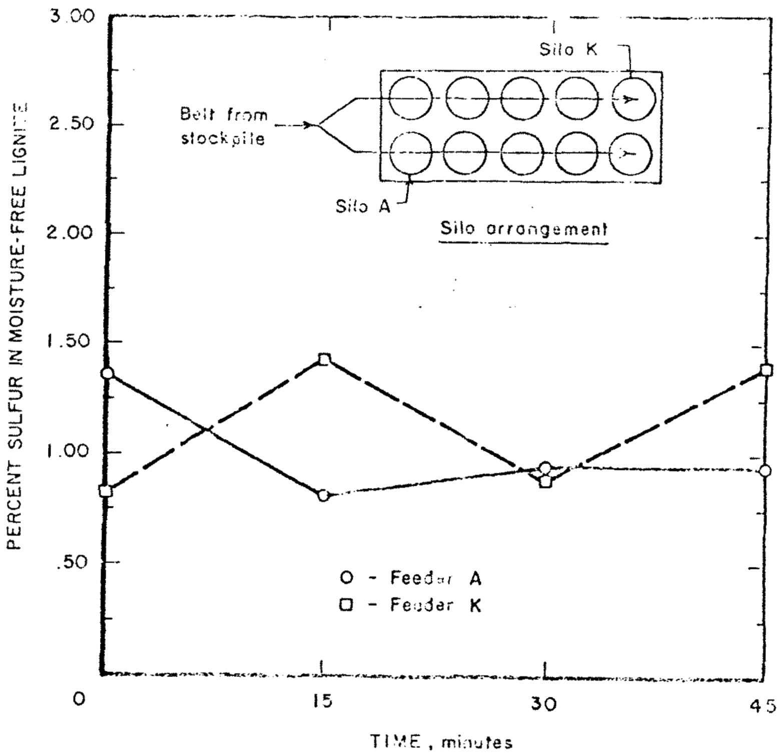

FIGURE 55. - Variation in sulfur content of lignite with time and point of sampling.

Special tests were run at both the Leland Olds and Milton R. Young plants to determine the variability of sulfur content in the lignite. At the Leland Olds plant, grab samples were collected at four 15-min intervals simultaneously from the two storage silos that were physically farthest apart. Each sample was split into four aliquots, two of which were analyzed by one laboratory and two by another. The results of the sulfur determinations at the two laboratories are shown in table 6, and the average of the four determinations for each sample is plotted in figure 55. The relative differences in sulfur contents of lignite between feeders at any given time or from a given feeder in a 15-min interval approach !

100 pct. Within- and between-laboratory results were usually within the ASTM tolerances of 0.05 and 0.10 percentage points, respectively. Similar results were found for data from the Milton R. Young plant.

TABLE 6. - Variation in sulfur content of lignite at the Leland Olds plant

Time, min	Silo	Sulfur concentration, pct moisture free				
		Lab. G		Lab. P		Average
		Sample 1	Sample 2	Sample 3	Sample 4	
0...........	A	1.49	1.34	1.33	1.41	1.39
	K	.76	.82	.93	.82	.83
15...........	A	.79	.77	.82	.85	.81
	K	1.42	1.25	1.55	1.56	1.45
30...........	A	.96	.94	.96	.96	.95
	K	.91	.91	.95	.94	.93
45...........	A	.90	.94	.97	1.01	.95
	K	1.37	1.37	1.46	1.46	1.42

The data indicate the difficulty in obtaining a representative lignite sample for sulfur balances. Sampling is a factor that is too often overlooked in powerplant testing, and some of the variation in data for the SO_2 tests could be attributed to nonrepresentative coal samples despite the emphasis placed on coal sampling.

SO_3 and SO_2 Sampling Procedure

Sulfur trioxide and SO_2 determinations were made by single point sampling in the flue gas ducts in each of the boilers tested. Usually the samples were collected in the duct between the boiler exit and the air heater, but some samples were collected after the air heater. In one case, samples were collected from the stack.

The apparatus used for SO_3 and SO_2 determination was similar to that described by Lisle and Sensenbaugh.[25] The flue gas is drawn through a condenser maintained at 140° to 194° F where the SO_3 is selectively condensed and collected. The flue gas then passes through a bubbler containing a 3-pct H_2O_2 solution. The resulting sulfuric acid is titrated to a methyl purple endpoint using a standard NaOH solution.

Orsat analyses were usually taken before and after each 30-min test for SO_2. All of the SO_2, SO_3, and NO_x values have been normalized to a 30-pct excess air basis for ease of comparison.

[25] Lisle, E. S., and J. D. Sensenbaugh. The Determination of Sulfur Trioxide and Acid Dew Point in Flue Gas. Combustion, v. 36, No. 7, January 1965, pp. 12-15.

NO_x Sampling Procedure

The NO_x sampling was usually done at or near the SO_2 sampling location. The procedure used was the Phenoldisulfonic acid method, specified as "Method 7" by the EPA in the Federal Register.[26] Because the test is more difficult to perform than the SO_2 test, fewer determinations were made.

Particulate Sampling and Study

During most of the tests, samples of fly ash were collected for determination of chemical analysis, particle size distribution, and, in later tests, for electrical resistivity. The fly ash samples were obtained from mechanical dust collector hoppers, pilot or commercial electrostatic precipitator hoppers, or from aspirated flue gas samples. Particle size analysis was done by the Bahco method and laboratory electrical resistivity measurements were by a method similar to that given in ASME PTC-28.[27] In the later tests, two "in situ" methods were used for resistivity studies. Details of these test procedures have been published.[28]

Results and Discussion

Summary of SO_3 Results

A total of 51 determinations of SO_3 content were made at the various lignite-burning plants. In most of these tests, a trace of SO_3 was detected but in no case did it exceed 1 ppm, even with SO_2 levels as high as 1,395 ppm. Such low SO_3 concentrations differ considerably from those published for eastern bituminous coals where it is normal for the SO_3 content to be 1 to 2 pct of the SO_2 content. The lack of free SO_3 in the flue gas from lignite-fired boilers is believed to be caused by the presence of reactive alkali in the fly ash. Any SO_3 produced rapidly reacts with the alkali to produce sulfates.

Summary of SO_2 Results

Data on the coal analysis, ash analysis, and SO_2 in the flue gas for the 46 test days are given in table 7. Included are data collected during 39 test days with pc firing, 5 days with cyclone firing, and 2 days with spreader-stoker firing. Figure 56 shows a frequency distribution of pounds of SO_2/MMBtu input for the test days, which include all variations in coal analysis, ash analysis, and firing method. For 17 of the test days, the SO_2 emissions levels were between 1.0 and 1.5 lb/MMBtu and for another 16 they were between 1.5 and 2.0 lb/MMBtu. For 13 test days, the SO_2 emissions were below the 1.2 lb/MMBtu national limit. There were only 7 test days in which the SO_2 was above 2 lb/MMBtu, at which level a 40-pct reduction would be required to meet the 1.2 lb/MMBtu level.

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[26] Work cited in footnote 23.

[27] American Society of Mechanical Engineers. Determining the Properties of Fine Particulate Matter. ASME PTC-28, New York, 1965, pp. 1[illegible]-17.

[28] Seele, S. J., P. H. Tufte, and G. H. Gronhovd. A Study of the Electrical Resistivity of Fly Ashes From Low-Sulfur Western Coals Using Various Methods. Pres. at Air Pollution Control Assoc. Meeting, Miami Beach, Fla., June 18-22, 1972. APCA Preprint 72-107, 1972, 31 pp.

TABLE 7. - Summary data for SO_2 emissions tests at lignite-fired plants

Test date	Boiler load, pct of rated capacity	Lignite analysis, pct: Moisture	Moisture-free basis: Ash	Sulfur	Carbon	Heating value, Btu/lb	Coal ash analysis, pct: SiO_2	Al_2O_3	CaO	Na_2O	SO_2 in flue gas: Number of tests	Average SO_2 ppm at 30 pct excess air	Lb SO_2 per MMBtu	Pct of input sulfur emitted
HOOT LAKE PLANT--BEULAH LIGNITE--PC FIRED														
7/25/65	80	35.6	10.3	1.09	65.4	10,830	14.2	9.8	20.1	8.2	4	420	0.93	48
7/28/65	82	35.9	10.1	1.03	65.4	10,840	14.4	10.2	21.1	9.0	4	450	1.00	52
8/16/65	82	36.7	9.9	1.15	65.4	10,900	17.0	11.4	26.0	1.7	2	800	1.76	84
8/18/65	84	36.6	10.2	1.10	65.8	10,970	19.7	12.0	26.3	1.6	2	850	1.83	92
9/7/65	102	36.1	11.9	1.36	NA	10,570	17.6	11.0	23.0	4.8	2	870	1.87	73
5/2/66	84	36.1	11.8	1.52	64.4	10,600	20.8	10.5	23.3	5.3	2	740	1.66	58
5/3/66	84	36.3	10.8	1.31	64.8	10,720	19.7	10.9	23.1	5.6	4	700	1.55	63
5/4/66	84	36.3	10.8	1.25	65.0	10,710	19.5	10.9	21.6	5.8	4	710	1.58	68
5/5/66	84	36.1	11.8	1.54	64.6	10,740	17.4	9.2	22.0	5.4	4	840	1.86	65
5/6/66	84	35.8	11.8	1.33	65.1	10,690	19.4	10.7	22.6	5.5	4	840	1.88	76
7/9/70	104	34.4	10.4	1.32	65.2	10,910	16.7	10.9	25.2	7.8	2	610	1.34	59
7/10/70	104	34.9	9.8	1.10	65.5	10,910	16.5	10.6	24.9	3.8	3	630	1.37	69
8/11/70	112	34.3	9.8	.92	64.1	10,670	14.6	10.6	21.2	7.5	1	515	1.14	66
8/12/70	112	34.5	9.8	.97	64.1	10,670	16.9	9.9	21.5	3.8	8	585	1.29	71
8/13/70	110	34.0	9.8	1.06	64.1	10,670	14.4	10.9	24.2	5.1	3	575	1.27	64
9/12/72	100	35.4	10.1	1.11	65.2	10,780	17.9	12.0	26.5	1.1	5	680	1.51	74
9/13/72	100	35.8	9.9	1.21	64.6	10,740	17.3	12.0	26.2	1.0	13	770	1.70	75
9/14/72	100	35.6	10.0	1.14	64.8	10,780	18.7	11.6	25.1	.9	13	820	1.81	86
9/15/72	100	35.2	9.8	1.03	65.4	10,800	18.9	12.1	28.2	9	10	780	1.74	91
9/18/72	84	35.7	10.9	1.14	63.9	10,530	20.6	11.5	20.3	6.1	12	600	1.34	61
9/19/72	84	35.7	10.3	1.03	64.5	10,680	19.7	11.2	20.0	6.1	22	570	1.27	66
9/20/72	84	35.2	10.4	1.12	64.4	10,660	20.1	11.5	21.2	6.1	9	550	1.22	59
HOOT LAKE PLANT--GASCOYNE LIGNITE--PC FIRED														
7/27/70	96	40.1	14.8	1.52	61.3	10,300	32.4	11.6	15.9	3.1	1	1,120	2.45	83
7/28/70	106	41.1	14.8	1.53	61.3	10,300	28.1	12.7	18.9	5.8	4	1,170	2.56	99
7/29/70	108	41.2	14.8	1.38	61.3	10,300	37.1	13.1	16.4	3.0	6	1,360	2.97	100
7/30/70	110	41.8	14.8	1.68	61.3	10,300	32.0	13.1	17.0	3.5	3	1,325	2.90	89
7/31/70	108	41.7	14.8	1.68	61.3	10,300	34.3	13.8	16.7	2.1	3	1,395	3.05	94
8/4/70	110	40.0	14.8	1.71	61.3	10,300	32.3	10.3	15.6	2.0	3	1,300	2.84	86
LELAND OLDS PLANT--GLENHAROLD LIGNITE--PC FIRED														
8/25/70	93	36.7	10.4	0.63	63.1	10,580	30.7	11.0	20.2	8.8	8	425	0.93	78
8/26/70	93	37.8	11.5	.65	62.9	10,570	31.4	11.8	17.0	8.0	4	470	1.03	84
8/27/70	84	35.2	11.1	.61	62.7	10,560	37.5	13.6	16.2	7.7	16	470	1.02	89
9/9/70	56	36.8	11.7	.85	62.5	10,580	35.1	13.6	17.7	6.0	16	655	1.42	89
9/10/70	55	36.4	11.7	.84	62.1	10,470	35.7	13.8	17.2	7.0	4	590	1.28	80
10/28/70	92	36.8	12.7	.75	62.3	10,425	35.3	13.4	18.7	6.2	6	520	1.14	79
10/29/70	100	38.1	12.1	.74	63.6	10,700	33.0	12.2	19.2	7.8	12	510	1.11	81
4/14/71	100	34.3	13.2	1.09	62.9	10,550	33.8	11.2	17.0	5.1	5	660	1.44	70
WM. J. NEAL PLANT--VELVA LIGNITE--PC FIRED														
7/27/71	100	NA	9.1	0.57	64.7	10,920	38.1	13.0	22.6	0.9	7	355	0.77	74
7/28/71	100	NA	9.1	.70	64.7	10,920	46.0	13.6	16.4	.8	9	525	1.14	89
7/29/71	100	NA	9.1	.66	64.7	10,920	34.1	14.5	23.4	.9	12	455	.99	82
MILTON R. YOUNG PLANT--BAUKOL-NOONAN (CENTER) LIGNITE--CYCLONE FIRED														
11/24/70	106	36.5	11.9	0.90	63.9	10,490	30.9	12.7	19.4	0.7	6	765	1.71	100
4/16/71	92	37.3	12.5	.93	62.9	10,580	29.1	13.3	21.8	.8	10	735	1.61	91
9/6/72	106	36.5	20.6	1.11	55.9	9,270	45.8	14.0	11.9	.4	5	930	2.02	86
9/7/72	106	37.1	19.4	.97	56.7	9,270	44.8	14.3	13.8	.4	17	785	1.76	82
9/8/72	106	38.2	13.8	1.10	59.2	9,550	29.9	10.9	19.4	.7	17	765	1.68	73
FRANKLIN P. WOOD PLANT--BAUKOL-NOON (LARSON) LIGNITE--SPREADER STOKER FIRED														
11/17/71	100	35.0	10.7	0.59	65.7	10,940	32.5	14.1	15.6	10.9	8	130	0.29	27
12/15/72	100	33.0	12.5	.54	64.7	10,880	32.8	14.4	16.8	8.6	18	194	.42	43

NA Not available.

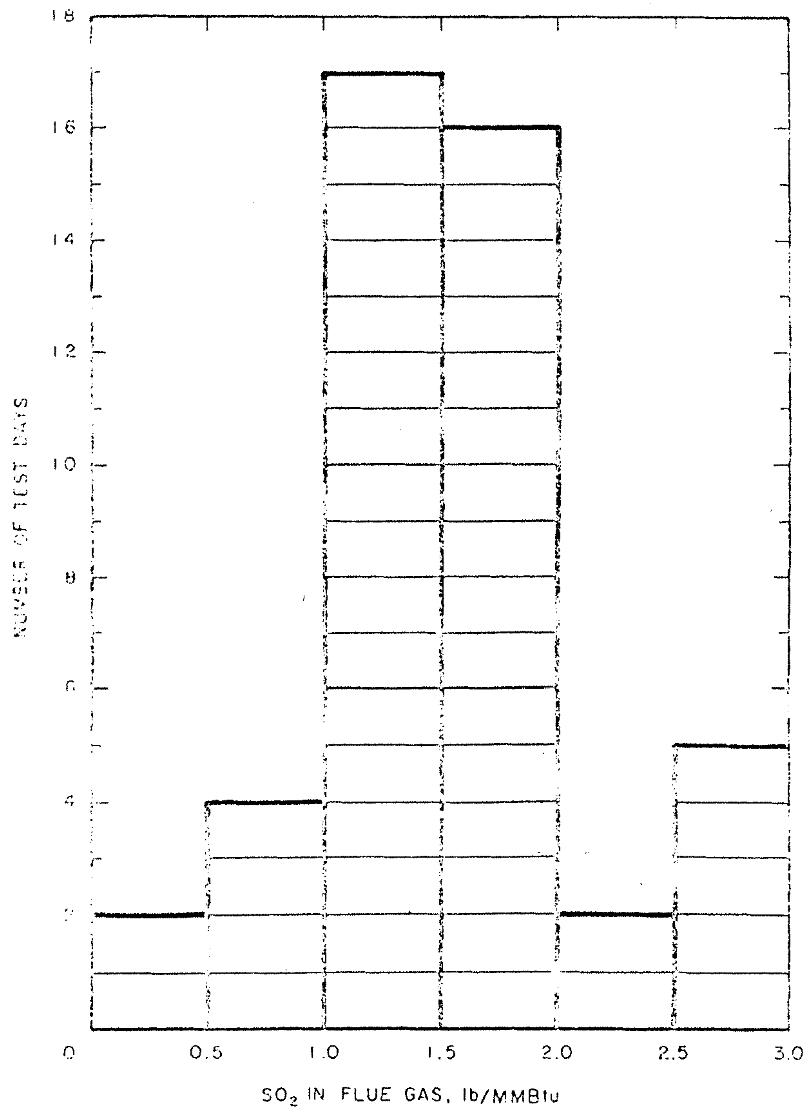

FIGURE 56. - Frequency distribution of SO_2 emission level.

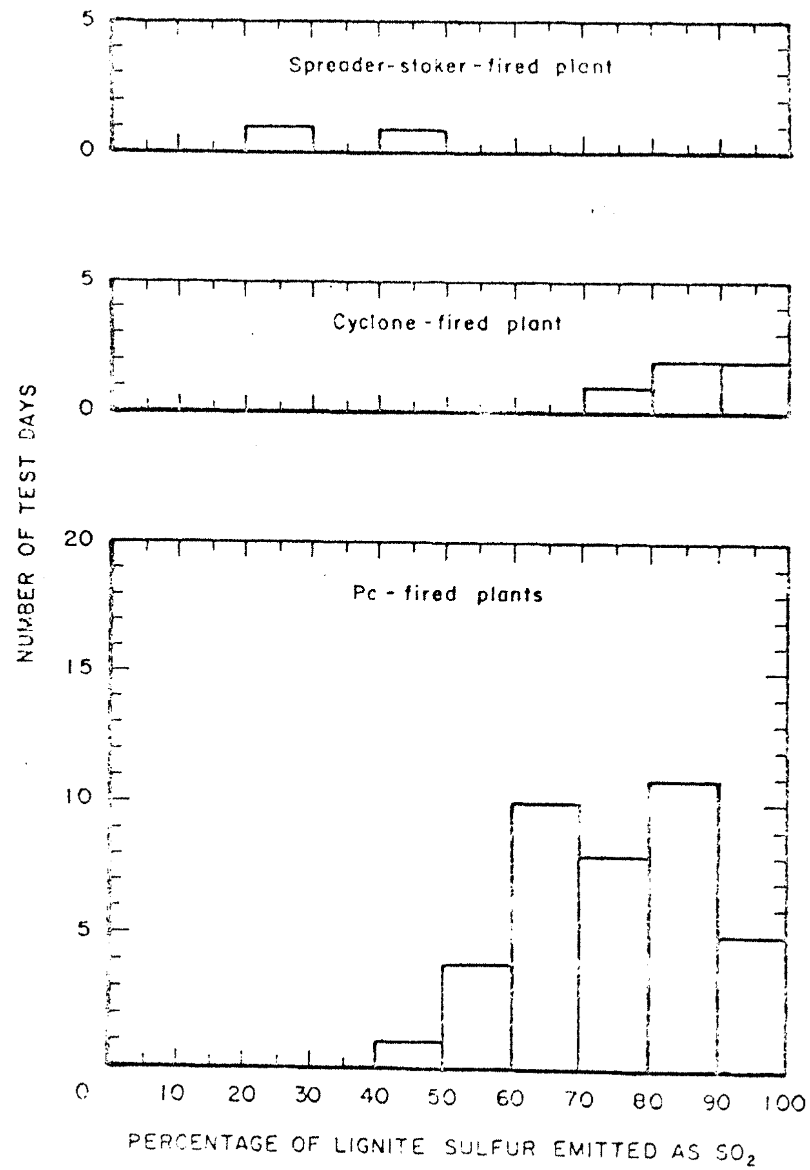

FIGURE 57. - Percentage of lignite sulfur emitted as SO_2.